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COFS III
MULTIBODY DYNAMICS AND CONTROL TECHNOLOGY*

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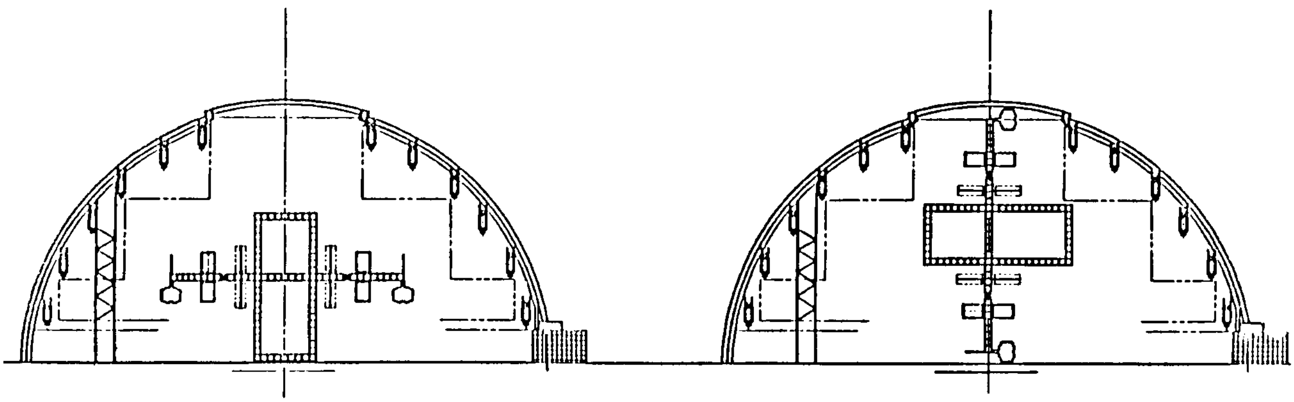
LOCKHEED MODEL DEFINITION STUDY
UPPER BOUND FOR REPLICA SCALE FACTOR

One of the results from the model definition study showed that the maximum scale factor for a replica model is .25. This is dictated by the fixed dimensions of the Large Spacecraft Laboratory or LSL (150 ft. height and 310 ft. diameter). Suspension analyses indicated the necessity to test the model in three planar orientations. The orientation depicted in the lower right-hand side of the figure requires the most test height, thus it limits the allowable scale factor.

SIZE OF LaRC LSL DICTATES A MAXIMUM SCALE FACTOR OF .25



MODEL DEFINITION STUDY: SCALING ANALYSIS

Replica scaling laws were applied to simplified theoretical models of joints and the joint/tube/joint system. The practical interpretation of the results for the specific Space Station configuration under study yielded a number of conclusions. One is that if proper replica scaling is employed, the nonlinear behavior of the joints can be scaled. Another is that the stiffness of the joint/tube/joint system is not strongly dependent on the stiffness of the highly preloaded, erectable joint because almost all of the strain energy is in the tube. For the configuration studied, the stiffness (and hence the mode shapes and frequencies) of the model depends on the material used and the model suspension to first order, while the joint dynamics, gravity preloads, and airloads are at worst second-order effects.

Theoretically, the damping in the joints due to friction and impact can probably be matched as well if perfect replica scaling is employed. However, the scaling laws require that the joints be machined to precisely scaled tolerances. In addition, the damping due to other dissipation mechanisms such as the suspension system may contribute to first order. Thus, it will be a challenge to obtain reliable damping data from the scale model.

- **MODE AND FREQUENCY DATA CAN BE OBTAINED**
- **OVERALL STIFFNESS NOT STRONGLY DEPENDENT ON JOINTS**
- **RELIABLE DAMPING DATA DIFFICULT TO OBTAIN**
  - **COMPLEX JOINT BEHAVIOR MAKES REPLICA SCALING DIFFICULT BELOW 1/4 SCALE**
  - **SUSPENSION MAY ACT AS TUNED MASS ABSORBER**

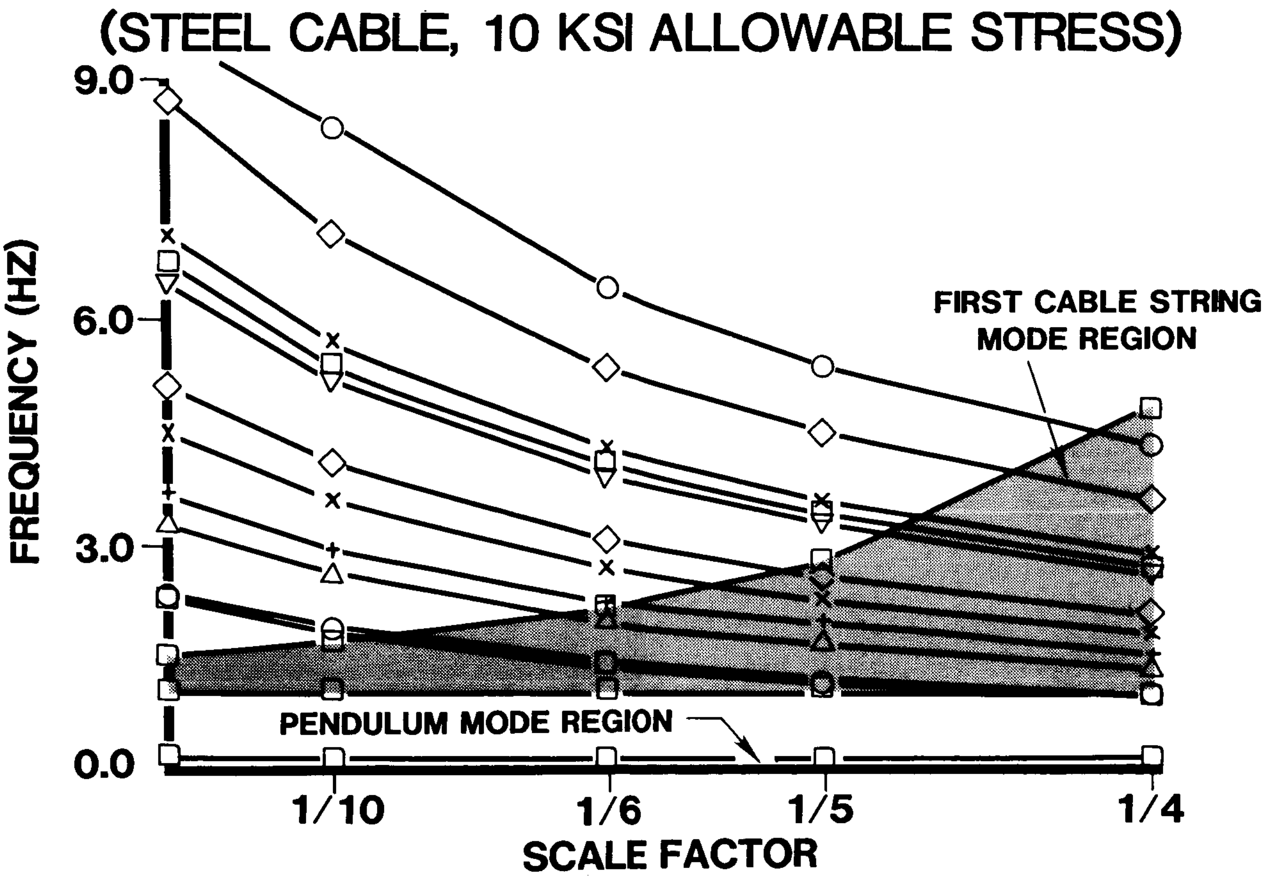
MODEL DEFINITION STUDY: SUSPENSION ANALYSIS

Detailed suspension analyses were conducted to evaluate the ability of the suspended scale model to emulate the dynamic behavior of the free-free Space Station. The results indicated only a slight preference for smaller scales. Significant suspension system interaction occurred for all of the scale factors studied, requiring that the model be suspended in 3 planar orientations in order to test for most of the modes. The study also identified a number of potential problems with the cables in the suspension system. The interaction of the suspension system complicates the interpretation of the test data and places an increased dependence on the analyst's ability to accurately model the suspension dynamics.

- **BEST TO SUSPEND MODEL AT LARGE RIGID MASSES & FLEXIBLE APPENDAGES**
- **SUSPENSION NEEDED IN 3 PLANAR ORIENTATIONS**
  - **MOST MODES PLANAR**
  - **SOME 3-D MODES MAY NOT BE OBTAINABLE**
  - **ACTIVE SUSPENSION WOULD BE HELPFUL**
- **POTENTIAL PROBLEMS WITH CABLES**
  - **MUST BE TUNED TO PRESCRIBED STRESS LEVEL (65 CABLES MIN.)**
  - **"STRING" MODE INTERACTION**
  - **CABLE WEIGHT**
  - **SPURIOUS MODES MAY COMPLICATE DATA INTERPRETATION**
- **SLIGHT PREFERENCE FOR SMALLER SCALES**

MODEL DEFINITION STUDY: FREQUENCY INTERACTIONS

This figure presents some of the results of the suspension system trade study. Detailed finite element models were used to analyze the scale model suspended by steel cables in the proposed LaRC Large Spacecraft Laboratory (LSL). The frequencies of the system modes of the ISS Space Station model are indicated by the set of monotonically decreasing lines. The line near the bottom of the plot indicates the rigid-body pendulum mode frequencies. The shaded area represents the 1st mode frequencies of the cable string modes. The range of frequencies is greater at larger scales due to the fact that the LSL has a constant height, providing larger models with a wider variation in cable lengths. The overlap of the system modes and the cable string modes illustrates the strong potential for the cables to function as tuned-mass dynamic absorbers, as mentioned previously.

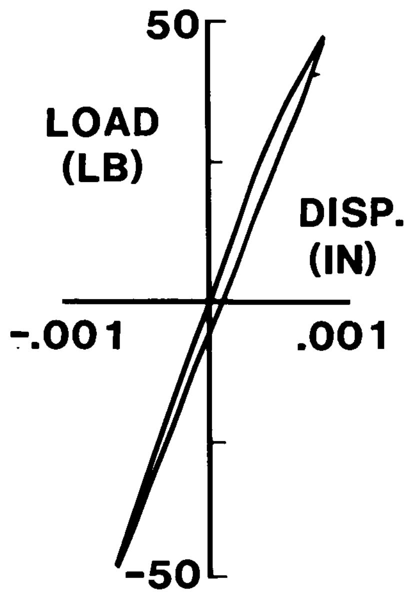


(INTERACTIONS BETWEEN SYS., PENDULUM, & CABLE MODE FREQ.)

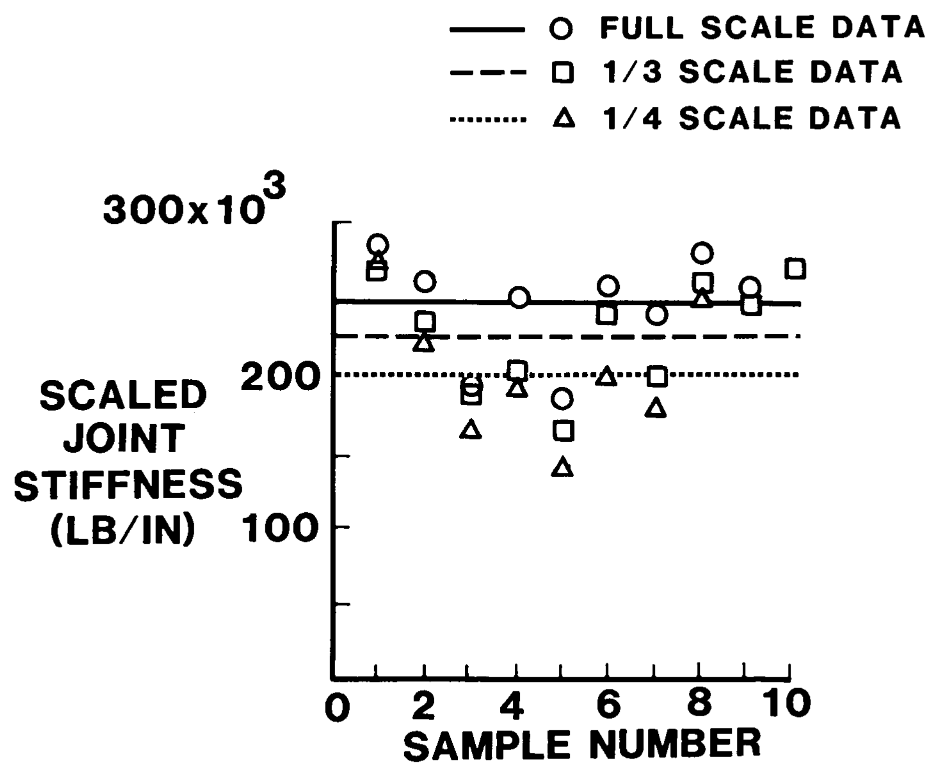
TEST DATA SHOW SCALED JOINTS PERFORM WELL

A candidate erectable Space Station joint was fabricated at full scale and at 1/4 and 1/3 scales in order to assess the comparability of the scaled joints to the full-scale behavior. The scaled joints were intended to be close replicas of the full scale; however, certain features such as screw threads and machining tolerances were not scaled. Static tests were performed on the various joints and the joint axial stiffness was computed from the measured test data. For replica scaling, the joint axial stiffness should scale linearly with the scale factor. Thus, a 1/4-scale joint should have one-fourth the stiffness of a full-scale joint. The test results showed appreciable scatter due to variability from joint to joint; however, on average the 1/3 and 1/4 scale joints were only 8% and 13% below the theoretical values, respectively. These results are encouraging and it is believed that with better control over fabrication procedures joint stiffness can be properly scaled.

Typical Joint Static Test Data



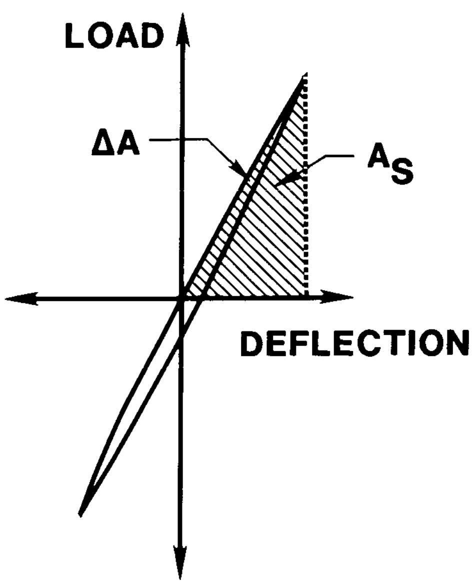
Variation in Joint Stiffness



JOINT DAMPING CORRELATIONS ENHANCED WITH INCREASED MODEL FIDELITY

Another important question is how well the inherent damping characteristics of the scaled joints compare to those of the full scale joint. Preliminary scaling analyses have shown that theoretically if replica conditions, then the damping energy loss factor should remain constant and independent of scale. This implies that all geometry, surface finish and tolerances be scaled, which is difficult in practice. A damping loss factor was computed for each size joint using the static test load deflection curves as depicted in the figure. On average the 1/3 and 1/4 scale joints were in error by 13% and 33% respectively. The larger error in the smaller joints is attributed to the tolerances which were not scaled. These results are encouraging; yet, it is noted that a series of dynamic tests need to be conducted in order to draw conclusions on the scaling of joint damping.

Typical Static Load–Deflection Test Data



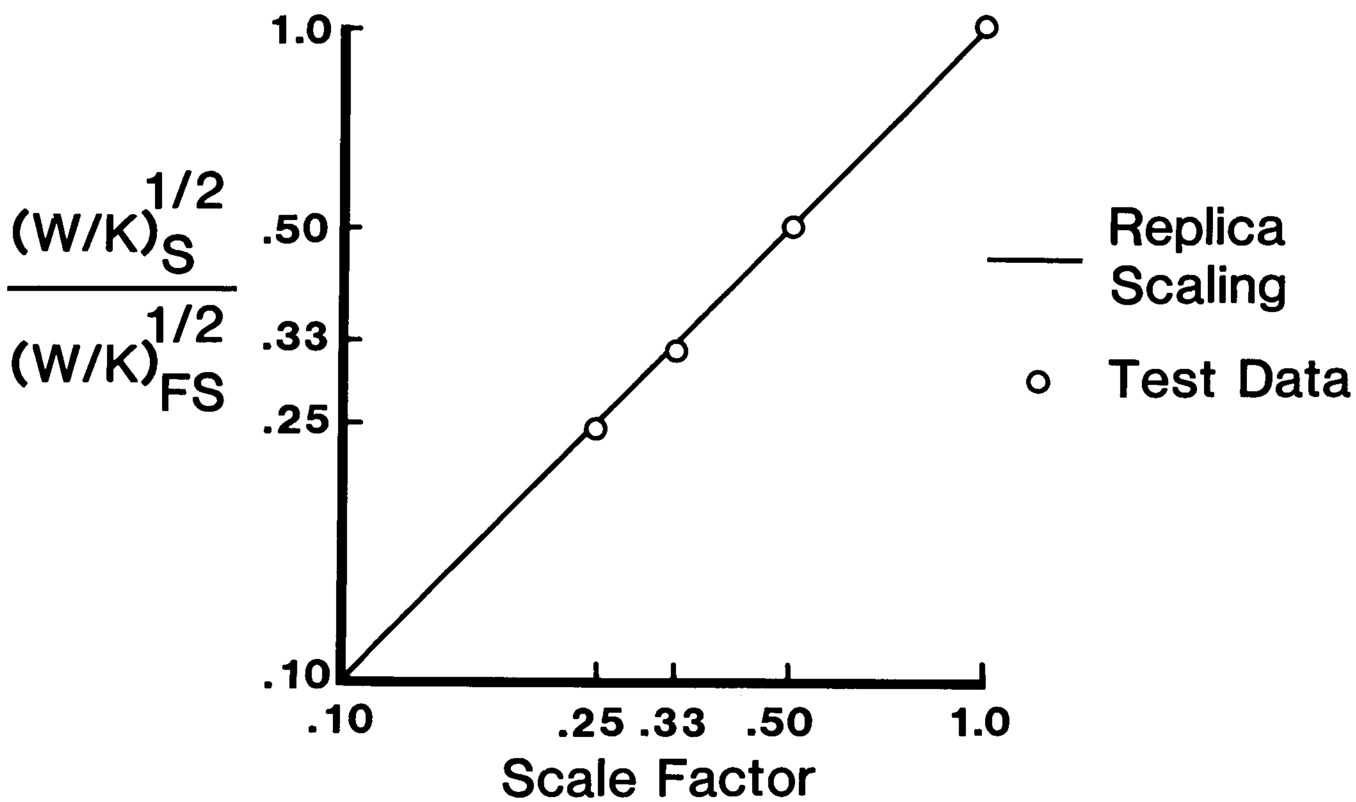
Damping Loss Factor (LF)

$$LF = \frac{\Delta A}{2\pi A_S}$$

JOINT	AVG. LF	% DIFF.
FULL SCALE	.030	-
1/3 SCALE	.026	13
1/4 SCALE	.040	33

GR/EP TUBES SCALED BY REDUCING NUMBER OF LAYERS

Graphite/epoxy tubes were fabricated at various scales to assess the feasibility of scaling Space Station truss members. A simple uni-directional lay-up was chosen for the full scale tubes. The scaled tubes were fabricated by reducing the number of layers proportionate to the scale factor. A measure of the performance of the scaled tubes is the tube weight to stiffness parameter. For replica scaling this parameter should vary with the square of the scale factor. Plotted in the adjoining figure is the ratio of the weight to stiffness for the scaled tubes to that of the full scale tubes raised to the 1/2 power, a quantity which should be linear for replica scaling. The preliminary test data show excellent correlation with the theoretical values.



MODEL DEFINITION STUDY: SCALE FACTOR RECOMMENDATIONS

The preliminary definition study yielded three separate scale factor recommendations for the scale model. Systems analyses favored a scale factor between 1/4 and 1/5 for a replica model, a scale factor of 1/5 for a model with simulated joints, and did not overwhelmingly favor a particular scale factor for a fully simulated model. Constructing a replica scale model maximizes the utility of the model for anticipated and as yet unanticipated tests. Given that the Space Station joints are still under development, it may be prudent to initiate the test program with simulated joints and then replace them with replica joints at a later date, if necessary.

- **REPLICA MODEL**
  - **COST CONSIDERATIONS FAVOR 1/4 SCALE**
  - **DYNAMIC CONSIDERATIONS FAVOR 1/5 SCALE**
- **SIMULATED MODEL WITH AN OPTION FOR LATER REPLICATION**
  - **RECOMMEND 1/5 SCALE**
- **FULLY SIMULATED MODEL (LINEAR JOINTS)**
  - **COMPARATIVELY LOW SENSITIVITY TO SCALE FACTOR**

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